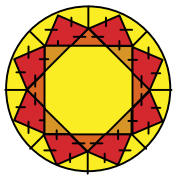


CCA
Common Component Architecture

An Overview of Components for Scientific Computing and Introduction to the Common Component Architecture

CCA Forum Tutorial Working Group
http://www.cca-forum.org/tutorials/
tutorial-wg@cca-forum.org



Goals of This Module

- Introduce basic concepts and vocabulary of component-based software engineering
- Highlight the special demands of high-performance scientific computing on component environments
- Introduce some terminology and concepts from the Common Component Architecture
- Provide a unifying context for the remaining talks
  - For those attending the extended CCA tutorial

Motivation: Modern Scientific Software Engineering Challenges

- **Productivity**
  - Time to first solution (prototyping)
  - Time to solution (“production”)
  - Software infrastructure requirements (“other stuff needed”)
- **Complexity**
  - Increasingly sophisticated models
  - Model coupling – multi-scale, multi-physics, etc.
  - “Interdisciplinarity”
- **Performance**
  - Increasingly complex algorithms
  - Increasingly complex computers
  - Increasingly demanding applications

Motivation: For Library Developers

- People want to use your software, but need wrappers in languages you don't support
  - Many component models provide language interoperability
- Discussions about standardizing interfaces are often sidetracked into implementation issues
  - Components separate interfaces from implementation
- You want users to stick to your published interface and prevent them from stumbling (prying) into the implementation details
  - Most component models actively enforce the separation

Motivation: For Application Developers and Users

- You have difficulty managing multiple third-party libraries in your code
- You (want to) use more than two languages in your application
- Your code is long-lived and different pieces evolve at different rates
- You want to be able to swap competing implementations of the same idea and test without modifying any of your code
- You want to compose your application with some other(s) that weren't originally designed to be combined

Some Observations About Software…

- "The complexity of software is an essential property, not an accidental one." *[Brooks]*
  - We can't get rid of complexity
- "Our failure to master the complexity of software results in projects that are late, over budget, and deficient in their stated requirements." *[Booch]*
  - We must find ways to manage it

More Observations…

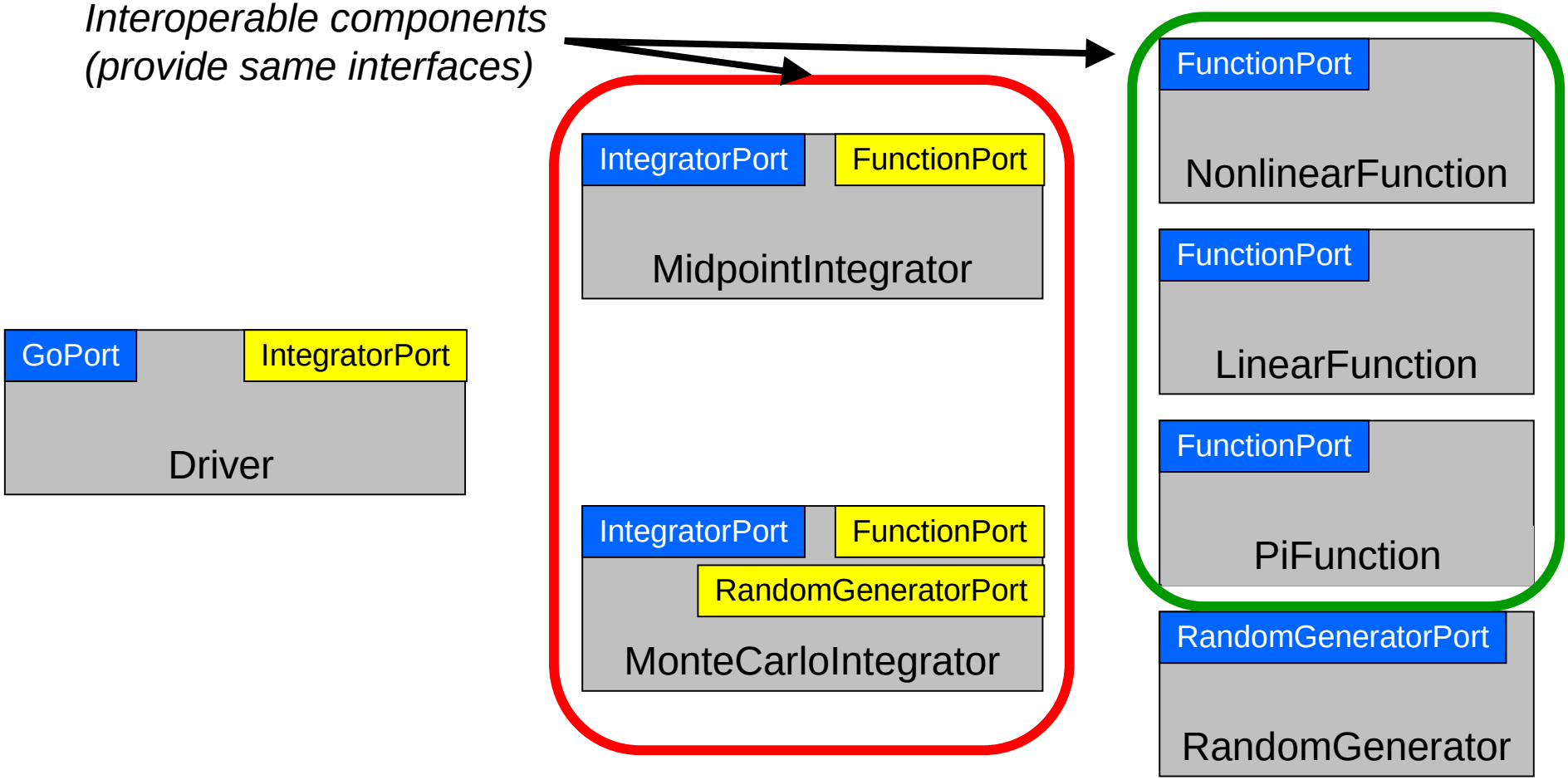
- "A complex system that works is invariably found to have evolved from a simple system that worked… A complex system designed from scratch never works and cannot be patched up to make it work." *[Gall]*
  - Build up from simpler pieces
- "The best software is code you don't have to write" *[Jobs]*
  - Reuse code wherever possible

Component-Based Software Engineering

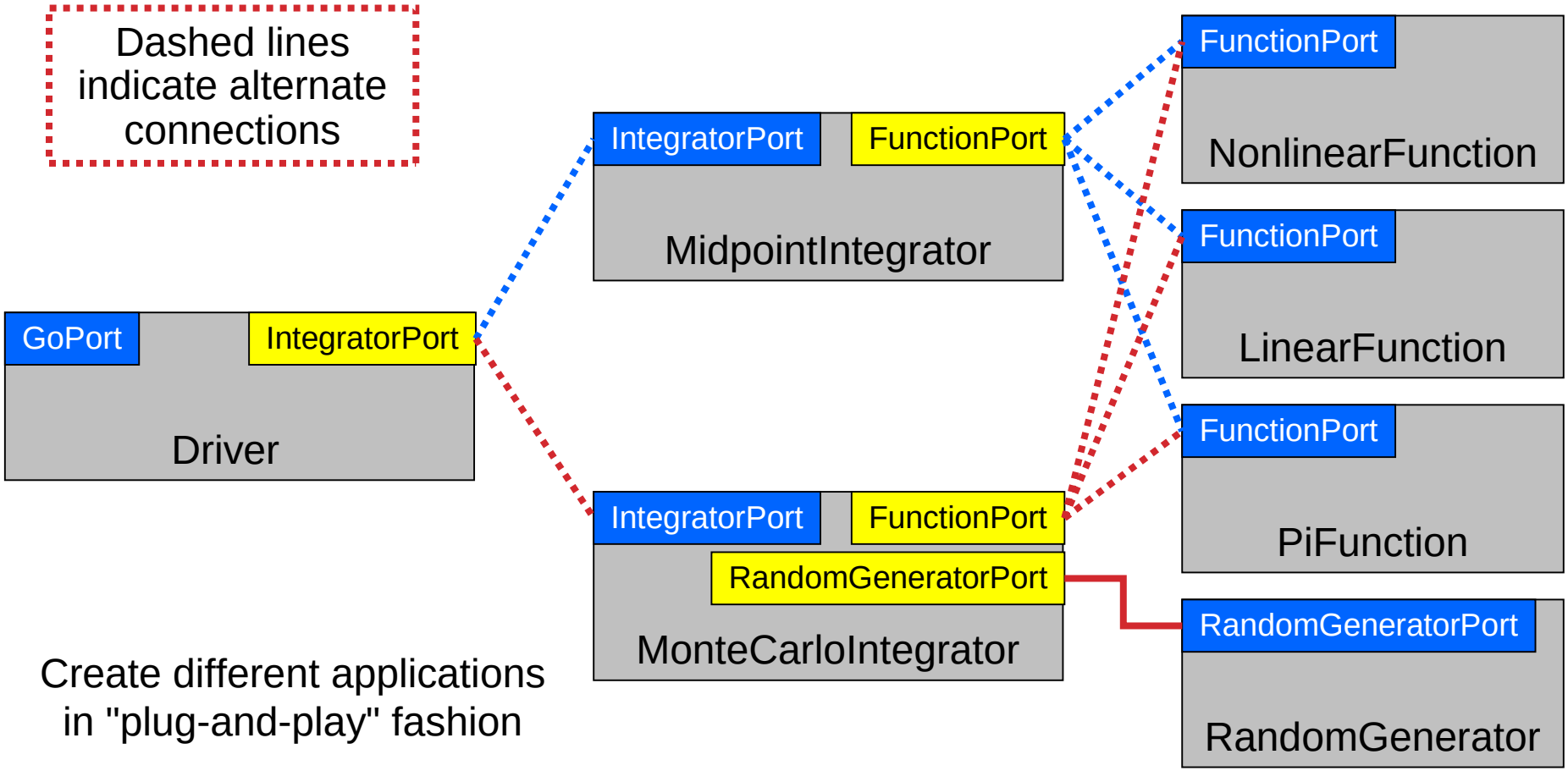
- CBSE methodology is emerging, especially from business and internet areas
- **Software productivity**
  - Provides a "plug and play" application development environment
  - Many components available "off the shelf"
  - Abstract interfaces facilitate reuse and interoperability of software
- **Software complexity**
  - Components encapsulate much complexity into "black boxes"
  - Plug and play approach simplifies applications
  - Model coupling is natural in component-based approach
- **Software performance** (indirect)
  - Plug and play approach and rich "off the shelf" component library simplify changes to accommodate different platforms

A Simple Example: Numerical Integration Components

Interoperable components (provide same interfaces)



Many Applications are Possible…



Create different applications in "plug-and-play" fashion

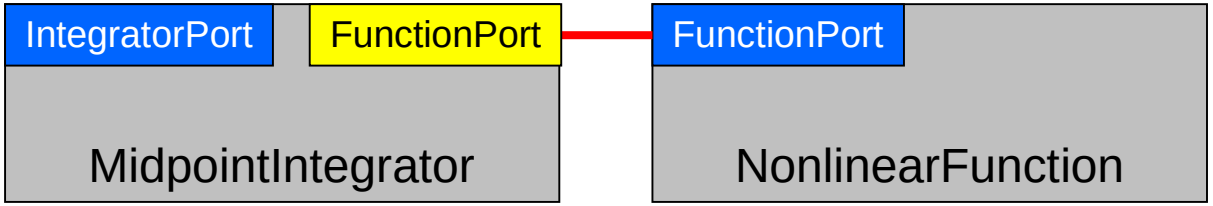
The "Sociology" of Components

- Components need to be shared to be truly useful
  - Sharing can be at several levels
    - Source, binaries, remote service
  - Various models possible for intellectual property/licensing
    - Components with different IP constraints can be mixed in a single application
- Peer component models facilitate collaboration of groups on software development
  - Group decides overall architecture and interfaces
  - Individuals/sub-groups create individual components

Who Writes Components?

- "Everyone" involved in creating an application can/should create components
  - Domain scientists as well as computer scientists and applied mathematicians
  - Most will also use components written by other groups
- Allows developers to focus on their interest/specialty
  - Get other capabilities via reuse of other's components
- Sharing components within scientific domain allows everyone to be more productive
  - Reuse instead of reinvention
- As a unit of publication, a well-written and –tested component is like a high-quality library
  - Should receive same degree of recognition
  - Often a more appropriate unit of publication/recognition than an entire application code

CCA Concepts: Components



- Components are a unit of software composition
  - Composition is based on interfaces (ports)
- Components provide/use one or more ports
  - A component with no ports isn't very interesting
  - Components interact via ports; implementation is opaque to the outside world
- Components include some code which interacts with the CCA framework
- The granularity of components is dictated by the application architecture and by performance considerations
- Components are peers
  - Application architecture determines relationships

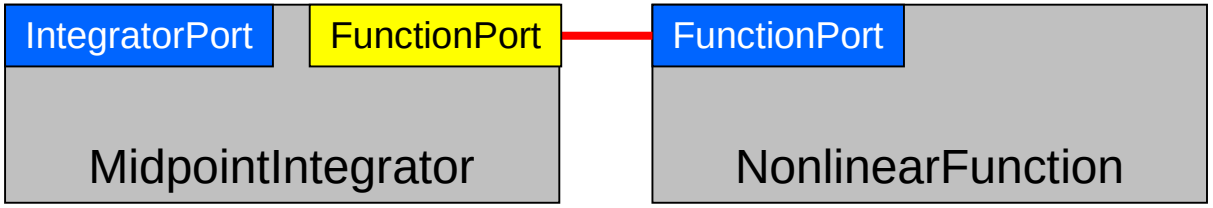
What is a Component Architecture?

- A set of standards that allows:
  - Multiple groups to write units of software (components)…
  - And have confidence that their components will work with other components written in the same architecture
- These standards define…
  - The rights and responsibilities of a component
  - How components express their interfaces
  - The environment in which are composed to form an application and executed (framework)
  - The rights and responsibilities of the framework

CCA Concepts: Frameworks

- The framework provides the means to "hold" components and compose them into applications
  - The framework is often application's "main" or "program"
- Frameworks allow exchange of ports among components without exposing implementation details
- Frameworks provide a small set of standard services to components
  - BuilderService allow programs to compose CCA apps
- Frameworks may make themselves appear as components in order to connect to components in other frameworks
- *Currently:* specific frameworks support specific computing models (parallel, distributed, etc.). *Future:* full flexibility through integration or interoperation

CCA Concepts: Ports



- Components interact through well-defined interfaces, or *ports*
  - In OO languages, a port is a class or interface
  - In Fortran, a port is a bunch of subroutines or a module
- Components may *provide* ports – implement the class or subroutines of the port ("Provides" Port)
- Components may *use* ports – call methods or subroutines in the port ("Uses" Port)
- Links denote a procedural (caller/callee) relationship, ***not dataflow!***
  - e.g., FunctionPort could contain: *evaluate(in Arg, out Result)*

Interfaces, Interoperability, and Reuse

- Interfaces define how components interact…
- Therefore interfaces are key to interoperability and reuse of components

- In many cases, “any old interface” will do, but…
- General plug and play interoperability requires multiple implementations providing the same interface

- Reuse of components occurs when they provide interfaces (functionality) needed in multiple applications

Designing for Reuse, Implications

- Designing for interoperability and reuse requires "standard" interfaces
  - Typically domain-specific
  - "Standard" need not imply a formal process, may mean "widely used"
- Generally means collaborating with others
- *Higher* initial development cost (amortized over multiple uses)
- Reuse implies longer-lived code
  - thoroughly tested
  - highly optimized
  - improved support for multiple platforms

Relationships: Components, Objects, and Libraries

- Components are typically discussed as objects or collections of objects
  - Interfaces generally designed in OO terms, but…
  - Component internals need not be OO
  - OO languages are not required
- Component environments can enforce the use of published interfaces (prevent access to internals)
  - Libraries can not
- It is possible to load several instances (versions) of a component in a single application
  - Impossible with libraries
- Components *must* include some code to interface with the framework/component environment
  - Libraries and objects do not

Domain-Specific Frameworks vs Generic Component Architectures

Domain-Specific

- Often known as "frameworks"
- Provide a significant software infrastructure to support applications in a given domain
  - Often attempts to generalize an existing large application
- Often hard to adapt to use outside the original domain
  - Tend to assume a particular structure/workflow for application
- Relatively common

Generic

- Provide the infrastructure to hook components together
  - Domain-specific infrastructure can be built as components
- Usable in many domains
  - Few assumptions about application
  - More opportunities for reuse
- Better supports model coupling across traditional domain boundaries
- Relatively rare at present
  - Commodity component models often not so useful in HPC scientific context

Special Needs of Scientific HPC

- Support for legacy software
  - How much change required for component environment?
- Performance is important
  - What overheads are imposed by the component environment?
- Both parallel and distributed computing are important
  - What approaches does the component model support?
  - What constraints are imposed?
  - What are the performance costs?
- Support for languages, data types, and platforms
  - Fortran?
  - Complex numbers? Arrays? (as first-class objects)
  - Is it available on my parallel computer?

Commodity Component Models

- CORBA, COM, Enterprise JavaBeans
  - Arise from business/internet software world

- Componentization requirements can be high
- Can impose significant performance overheads
- No recognition of tightly-coupled parallelism
- May be platform specific
- May have language constraints
- May not support common scientific data types

What is the CCA? (User View)

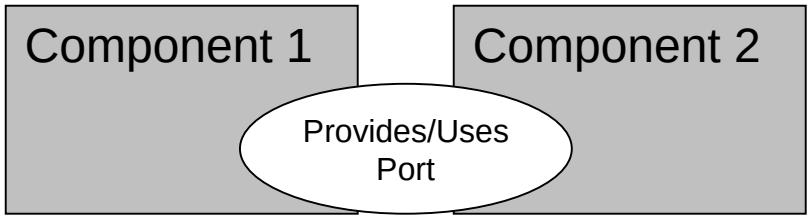
- A component model specifically designed for high-performance scientific computing
- Supports both parallel and distributed applications
- Designed to be implementable without sacrificing performance
- Minimalist approach makes it easier to componentize existing software

What is the CCA? (2)

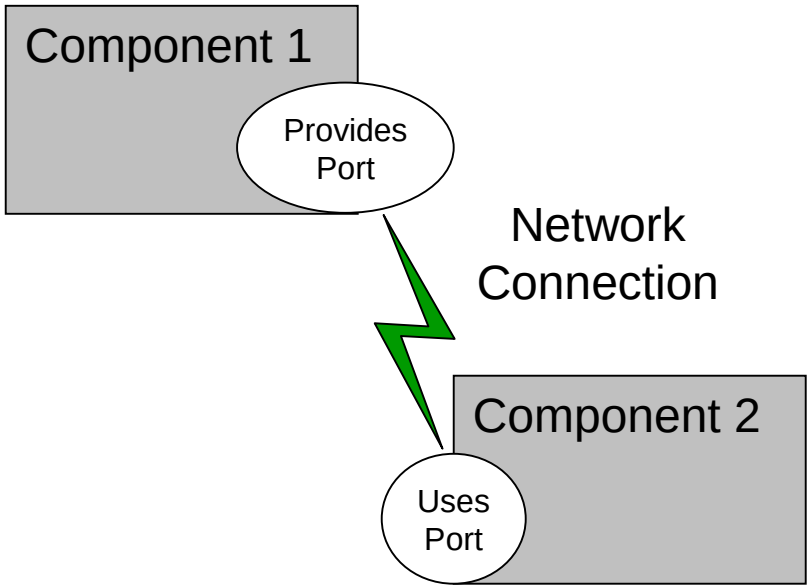
- Components are peers
- *Not* just a dataflow model
- A *tool* to enhance the productivity of scientific programmers
  - Make the hard things easier, make some intractable things tractable
  - Support & promote reuse & interoperability
  - Not a magic bullet

Importance of Provides/Uses Pattern for Ports

- Fences between components
  - Components must declare both what they provide and what they use
  - Components cannot interact until ports are connected
  - No mechanism to call anything not part of a port
- Ports preserve high performance direct connection semantics…
- …While also allowing distributed computing



Direct Connection

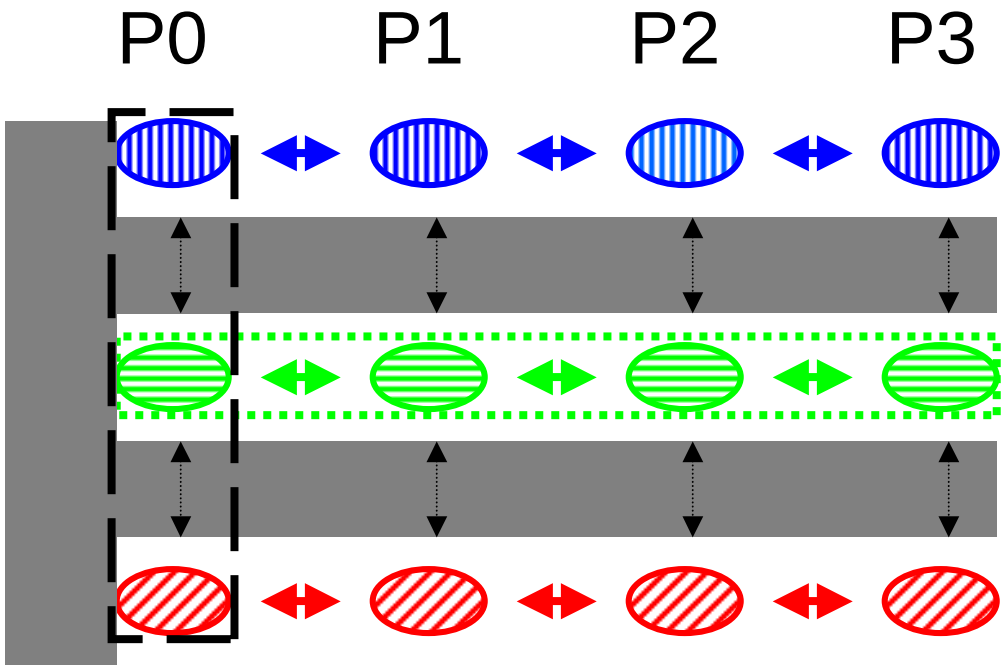


CCA Concepts: "Direct Connection" Maintains Local Performance

- Calls *between* components equivalent to a C++ virtual function call: lookup function location, invoke it
  - Cost equivalent of ~2.8 F77 or C function calls
  - ~48 ns vs 17 ns on 500 MHz Pentium III Linux box
- Language interoperability can impose additional overheads
  - Some arguments require conversion
  - Costs vary, but small for typical scientific computing needs
- Calls within components have no CCA-imposed overhead
- **Implications**
  - Be aware of costs
  - Design so inter-component calls do enough work that overhead is negligible

CCA Concepts: Framework Stays "Out of the Way" of Component Parallelism

- Single component multiple data (SCMD) model is component analog of widely used SPMD model
- Each process loaded with the same set of components wired the same way
- Different components in same process "talk to each" other via ports and the framework
- ***Same component in different processes talk to each other through their favorite communications layer (i.e. MPI, PVM, GA)***



Components: Blue, Green, Red

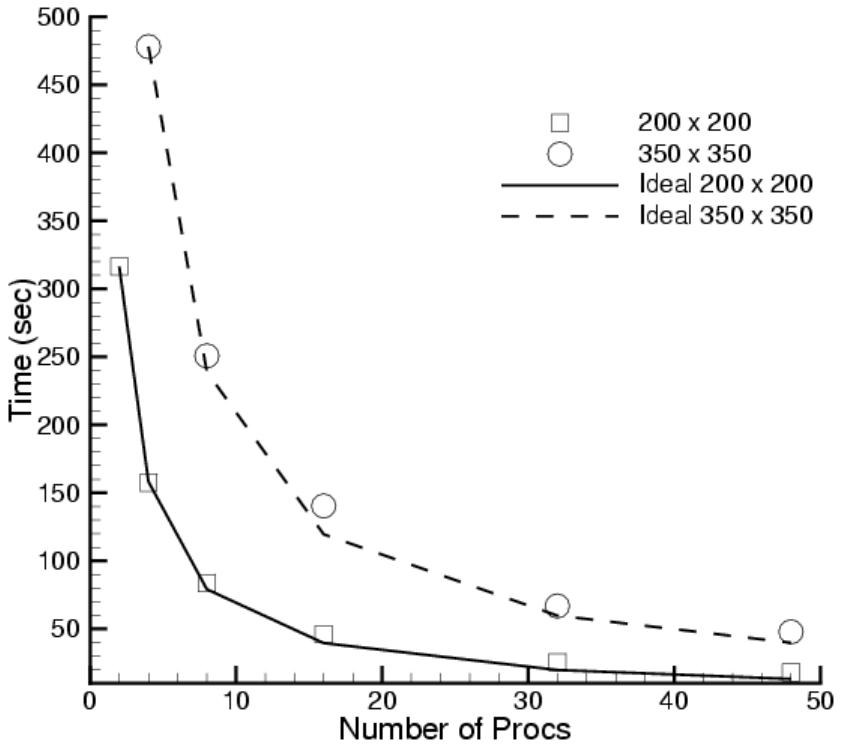
Framework: Gray

MCMD/MPMD also supported

Other component models ignore parallelism entirely

Scalability of Scientific Data Components in CFRFS Combustion Applications

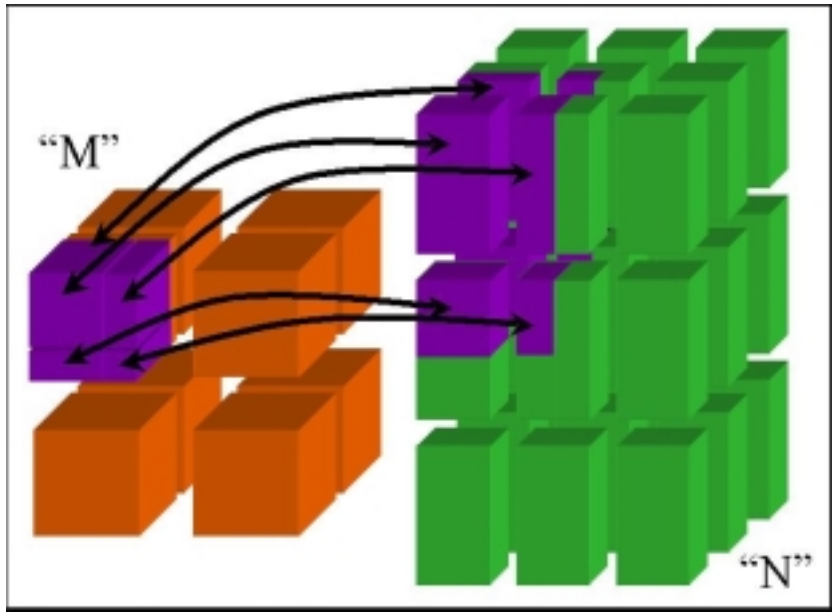
- Investigators: S. Lefantzi, J. Ray, and H. Najm (SNL)
- Uses GrACEComponent, CvodesComponent, etc.
- Shock-hydro code with no refinement
- 200 x 200 & 350 x 350 meshes
- Cplant cluster
  - 400 MHz EV5 Alphas
  - 1 Gb/s Myrinet
- Negligible component overhead
- Worst perf : 73% scaling efficiency for 200x200 mesh on 48 procs



Reference: S. Lefantzi, J. Ray, and H. Najm, Using the Common Component Architecture to Design High Performance Scientific Simulation Codes, *Proc of Int. Parallel and Distributed Processing Symposium*, Nice, France, 2003, accepted.

CCA Concepts: MxN Parallel Data Redistribution

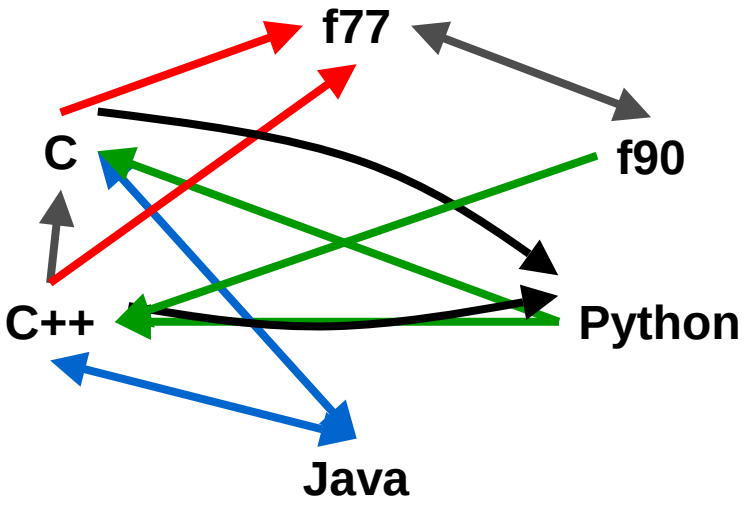
- Share Data Among Coupled Parallel Models
  - Disparate Parallel Topologies (M processes vs. N)
  - e.g. Ocean & Atmosphere, Solver & Optimizer…
  - e.g. Visualization (Mx1, increasingly, MxN)

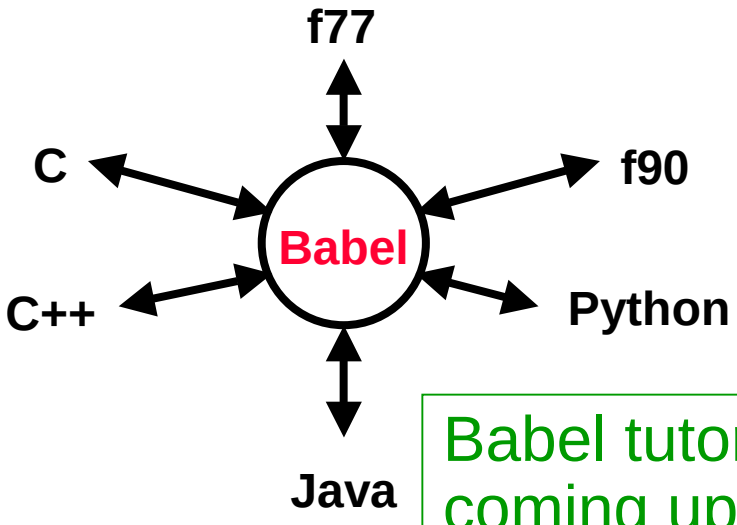


Research area -- tools under development

CCA Concepts: Language Interoperability

- Existing language interoperability approaches are "point-to-point" solutions
- Babel provides a unified approach in which all languages are considered peers
- Babel used primarily at interfaces





Babel tutorial coming up!

Few other component models support all languages and data types important for scientific computing

What the CCA isn't…

- CCA doesn't specify who owns "main"
  - CCA components are peers
  - Up to application to define component relationships
    - "Driver component" is a common design pattern
- CCA doesn't specify a parallel programming environment
  - Choose your favorite
  - Mix multiple tools in a single application
- CCA doesn't specify I/O
  - But it gives you the infrastructure to create I/O components
  - Use of stdio may be problematic in mixed language env.
- CCA doesn't specify interfaces
  - But it gives you the infrastructure to define and enforce them
  - CCA Forum supports & promotes "standard" interface efforts
- CCA doesn't require (but does support) separation of algorithms/physics from data

What the CCA *is*…

- CCA is a *specification* for a component environment
  - Fundamentally, a design pattern
  - Multiple “reference” implementations exist
  - Being used by applications
- CCA increases productivity
  - Supports and promotes software interopability and reuse
  - Provides “plug-and-play” paradigm for scientific software
- CCA offers the flexibility to architect your application as you think best
  - Doesn’t dictate component relationships, programming models, etc.
  - Minimal performance overhead
  - Minimal cost for incorporation of existing software
- CCA provides an environment in which domain-specific application frameworks can be built
  - While retaining opportunities for software reuse at multiple levels

Review of CCA Terms & Concepts

- **Ports**
  - Interfaces between components
  - Uses/provides model
- **Framework**
  - Allows assembly of components into applications
- **Direct Connection**
  - Maintain performance of local inter-component calls
- **Parallelism**
  - Framework stays out of the way of parallel components
- **MxN Parallel Data Redistribution**
  - Model coupling, visualization, etc.
- **Language Interoperability**
  - Babel, Scientific Interface Definition Language (SIDL)

Summary

- Components are a software engineering tool to help address software productivity and complexity
- Important concepts: components, interfaces, frameworks, composability, reuse
- Scientific component environments come in “domain specific” and “generic” flavors
- Scientific HPC imposes special demands on component environments
  - Which commodity tools may have trouble with
- The Common Component Architecture is specially designed for the needs of HPC